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Synthesis and characterization of one-dimensional GaN nanostructures

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Abstract

One-dimensional GaN nanostructures were successfully synthesized, employing Ga_2O_3 as the initial material. GaN nanowires and nanobelts were obtained via chemical-vapour-deposition (CVD) method and had been characterized by X-ray diffraction (XRD), scanning electron microscopy (SEM) and high resolution transmission electronic microscope (HRTEM). The Raman spectra of GaN nanowires and nanobelts were analysed. The influences of different technological parameters to the morphology of GaN were studied.

Keywords: A1. Characterization; A1. Crystal morphology; A2. Growth from vapour; B1. Nitrides; B2. Semiconducting III–V materials

1. Introduction

GaN is a wide gap semiconductor with a direct energy band gap of 3.4 eV at room temperature. GaN, the representative of the III–V generation semiconductors, possesses many excellent properties, such as quick saturated speed of the electronics drift, small intervene electricity constant, excellent heat and chemical stability, undissolved in the water/sour/alkali at room temperature, well transmit heat function and mechanical functions [1–6]. GaN is an ideal material for the fabrication of high frequency, high power, high density integrated electronic device and high brightness blue/green light emitting diodes (LED) and laser diodes (LD) [7,8]. In the past 30 years, developing blue/green semiconductor light emitting device was one of the research directions in the academic and industry fields. This kind of emitting device has great potential market because it can be applied extensively in the realms of lighting, signal indicator, flat display, colour copy, colour scanning, light data storage and pharmacy, etc. The research of one-dimensional GaN nanostructures was developed relatively late. According to the reports, the template method was mostly applied to prepare the GaN one-dimensional nanomaterials. In 1997, Fan group obtained single-crystal GaN nanorods in restricted space, employing carbon nanotubes as template. Its diameter was about 15 nm [9]. In other reports, GaN nanorods were prepared by using the mixture of Ga_2O_3 and Ga as initial materials to react with NH_3 at high temperature when utilizing multi-holes Al_2O_3 as template [10,11]. GaN nanorods were prepared by utilizing GaAs nanorods as template [12]. In 2000, the researcher continuously reported that one-dimensional GaN nanostructures were directly synthesized without template in open space, which became a critical step for nanomaterial research. In addition, it was reported that Ga/GaN reacted with ammonia to fabricate GaN nanobelts by using Fe/B_2O_3 as a catalyst [13–16], the metal gallium directly reacted with ammonia to fabricate GaN nanobelts [17].

In this paper, we have synthesized GaN nanowires and nanobelts via chemical-vapour-deposition (CVD) method, using ball-milling Ga_2O_3 powder as material. The Raman spectra of GaN nanowires and nanobelts were also analysed. The influences of different experimental parameters to the morphology of GaN were studied. Especially, the influences of the shape of quartz boat to the morphology of GaN nanostructures were investigated.

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2. Experimental procedure

2.1. Preparation of GaN nanowires

Ball-milling Ga_2O_3 powder with a purity of no less than 99.9% was used as the initial material. Experiment system adopted the traditional level tube furnace. A quartz tube was placed in the constant temperature region of the level furnace. An unpolished, single crystal slice ($5 \times 5 \times 0.5\,mm^3$) $LaAlO_3$ was the substrate. The material and substrate were placed in the quartz boat with an open structure. Experimental steps are as follows: (1) Placing 3 g of Ga_2O_3 and the substrate in the quartz boat. The material is apart from the substrate of about 5–15 mm and lies in the windward of substrate. Pushing the quartz boat into the central of the quartz tube. (2) The tube furnace was pumped vacuum. Then high purity argon (Ar) gas with a flow rate of 15 SCCM (standard cubic centimetre every minute) was introduced into the quartz tube. The quartz tube was heated to 1050 °C in a furnace. After that maintaining the Ar gas at the original flow rate, NH_3 gas with a rate of 15 SCCM was simultaneously sent into the quartz tube. (3) The temperature was maintained at 1050 °C for 45 min. Then cooling with the constant Ar/NH_3 flow rate to room temperature naturally. Finally, take the substrate out of the quartz tube to analyse.

2.2. Preparation of GaN nanobelts

The experimental method and basic experimental steps that had been adopted were similar to the preparation of GaN nanobelts. Experiment system was still the traditional level tube furnace. A quartz tube was placed in the furnace. An unpolished, single crystal slice ($5 \times 5 \times 0.5\,mm^3$) $LaAlO_3$ was as substrate. Material and substrate were placed in the quartz boat with a half-open structure (Note: the shape of quartz boat is different from that used in the preparation of GaN nanowires). The experimental parameters were similar to those chosen preparing the GaN nanowires.

The composition of GaN nanostructures was analysed by X-ray electronic colour scattering energy spectrum instrument, which is equipped by field emitting scanning electron microscopy (FE-SEM) (Hitachi (Tokyo, Japan) S-4200). The crystal phase of GaN nanostructures was characterized by a Rigaku (Tokyo, Japan) D/max-2400 X-ray diffraction (XRD) instrument, which uses Cu Kα radiation ($\lambda = 1.54178\,\text{Å}$). Structure of GaN nanostructures was characterized by Hitachi (Tokyo, Japan) S-4200 FE-SEM. The microstructures of GaN nanostructures were analysed by transmission electron microscopy Philip CM12/Philip CM200s. Modes of GaN were analysed by Raman. Raman spectrum was obtained using the Raman scattering spectrum device (JY-64000).

3. Results and discussion

3.1. Composition and phase analysis

(1) The composition of GaN nanowires and nanobelts: The composition of GaN nanowires and nanobelts was studied by EDX (X-ray scattering electron energy spectrum equipped with SEM). EDX spectra are shown in Fig. 1. According to Fig. 1(a) and (b), we concluded that both nanowires and nanobelts were composed of N and Ga element. The atom ratio of N/Ga is 1:1.
(2) The phase analysis of GaN nanowires and nanobelts: The phase of GaN nanowires and nanobelts was analyzed by XRD. One peak, which is marked "*" in Fig. 2, was produced by the $LaAlO_3$ substrate, the other remaining peaks, of both GaN nanowires and nanobelts, were attributed to the hexagonal structures of GaN (card number: ICDD PDF No.50-0792).

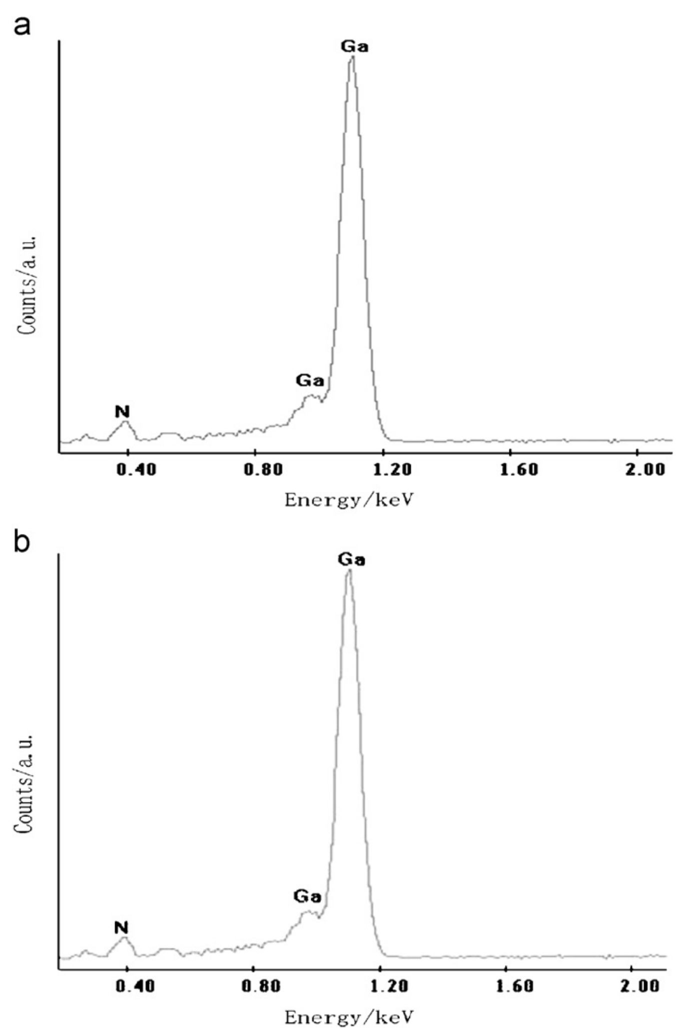

Fig. 1. EDX spectrum of (a) GaN nanowires and (b) GaN nanobelts.